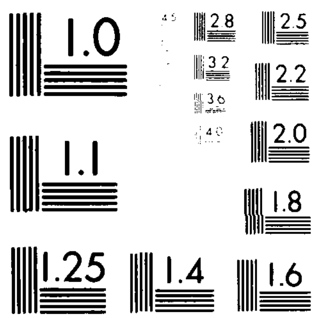
AD-A088 286 FREQUENCY ELECTRONICS INC NEW HYDE PARK N Y F/G 9/1
VIBRATION RESISTANT QUARTZ CRYSTAL RESONATORS.(U)
JUL 80 B GOLDFRANK, A WARNER DAAK20-79-C-0272
UNCLASSIFIED DELET-TR-79-0272-1 NL

1 OF 1
AD
A088286

END
DATE
FILMED
9-80
DTIC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

LEVEL

AD A088286

Research and Development Technical Report

DELET-TR-79-0272-1

VIBRATION RESISTANT QUARTZ CRYSTAL RESONATORS

B. Goldfrank
A. Warner

FREQUENCY ELECTRONICS, INC.
3 Delaware Drive
New Hyde Park, NY 11040

July 1980

DISTRIBUTION STATEMENT

Approved for public release;
distribution unlimited.

Prepared for:
ELECTRONICS TECHNOLOGY & DEVICES LABORATORY

ERADCOM

US ARMY ELECTRONICS RESEARCH AND DEVELOPMENT COMMAND
FORT MONMOUTH, NEW JERSEY 07703

NOTICES

Disclaimers

Disposition

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER: DELET-TR-79-0272-1	2. GOVT ACCESSION NO.: AD-A088 386	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle): Vibration Resistant Quartz Crystal Resonators		5. TYPE OF REPORT & PERIOD COVERED: 1st 6 Months 27 Aug 79 to 27 Feb 80
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): B. Goldfrank, A. Warner		8. CONTRACT OR GRANT NUMBER(s): DAAK20-79-C-0272
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Frequency Electronics, Inc. 3 Delaware Drive New Hyde Park, NY 11040		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 1L162705AH94 101102
11. CONTROLLING OFFICE NAME AND ADDRESS: U.S. Army Electronics Technology and Devices Laboratory Attn: DELET-MQ Fort Monmouth, NJ 07703		12. REPORT DATE: July 1980
		13. NUMBER OF PAGES: 25
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report): UNCLASSIFIED
		15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Low "g" Sensitivity Crystal Units and Their Testing By A. Warner, B. Goldfrank, M. Meirs and M. Rosenfeld.
Further Developments on 'SC' Cut Crystals By B. Goldfrank and A. Warner.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Doubly rotated quartz crystals, Low 'g' sensitivity, Fast warm-up crystal resonators, quartz, quartz crystals, quartz resonators, SC cut, acceleration, vibration

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The objectives of this investigation are to provide doubly rotated quartz crystal resonators that exhibit fast warm-up and low 'g' sensitivity. Warm-up is to be on the order of 1 PP10^9 in three minutes. The 'g' sensitivity is to be 1 PP10^{10} maximum in any axis.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-014-6601

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

CONTENTS

		Page
ABSTRACT		
	INTRODUCTION	1
1.	TASK OBJECTIVES	2
2.	APPROACH	5
3.	PROGRAM PROGRESS	6
4.	TEST RESULTS AND EVALUATIONS	7
5.	PROPOSED OBJECTIVES FOR NEXT SIX-MONTH PERIOD	12

LIST OF FIGURES

FIGURE NO.	NOMENCLATURE	PAGE
I-1	Nonactive bond well located. Both active bonds slightly high. One active bond toward right side of flat.	14
I-2	Nonactive bond high and to right. Active bonds high, and one slightly to right. One ribbon has excess material above crystal flat.	15
I-3	Nonactive bond and one active bond are high other active bond is centrally located. Small kink in active bond that is high.	16
I-4	All bonds are high. One active bond partially off ribbon. Other active bond has slight kink in ribbon.	17
I-5	All bonds slightly high. One active bond slightly to right. Excess ribbon on one active bond.	18

INTRODUCTION

This is the first six-month report under Contract DAAK20-79-C-0272, for the development of doubly rotated quartz crystals. Included in the report are the major accomplishments during the first six-month period and detailed results of the aforementioned accomplishments. Also included is a list of proposed objectives for the next six-month period. This report is broken down into sections covering the various categories listed below:

1. Task Objectives
2. Approach
3. Program Progress
4. Test Results and Evaluations
5. Proposed Objectives for Next Six-Month Period.

1. TASK OBJECTIVES

A. General

Modern communications, navigation and surveillance systems require highly stable quartz crystal reference oscillators. These oscillators must be capable of fast warmup, and must possess low acceleration sensitivities.

Currently available quartz crystal resonators exhibit frequency changes of about 2 parts in 10^9 per g of acceleration. Such an acceleration sensitivity, a consequence of stress sensitivity of quartz, has been shown to have serious detrimental consequences in several applications where the resonator must operate in a vibratory environment. It has recently been shown that doubly rotated quartz crystal resonators, particularly the so-called SC cut, have much lower sensitivity to mechanical stresses than the commonly used (singly rotated) AT cut. It therefore seems probable that lower acceleration sensitivities will be achieved by using doubly rotated cuts.

The major objective of this program is to study the properties of doubly rotated cuts, and to develop vibration resistant, high precision resonator designs. The optimized vibration resistant designs shall be selected based on suitability for meeting the performance requirements of the NAVSTAR Global Positioning System Manpack/Vehicular Set. The development effort shall make extensive use of previously published information.

B. Definitions of the Angles of Cut

The angles of cut of doubly rotated plates can be described by the IEEE notation as (YXWl)ϕ/θ. This notation is explained in "Standards of Piezo-electric Crystals, 1949", Proc, IRE, Vol. 37, Dec 1949, pp. 1378-1395, and in IEEE Standard No. 176-1949. An SC cut, for example, may be described as (YXWl) 21.75°/33.91°. For simplicity, a cut may also be specified by stating the two rotation angles only; e.g., ϕ = 21.75°, θ = 33.91° describes the same SC cut.

C. Requirements

1. Resonator Frequencies

Optimized vibration resistant designs shall be developed for three resonator frequency ranges as follows:

a. 5 MHz

b. 10 MHz

c. 20 MHz

2. Properties to be Studied and Objectives

The properties of quartz crystal resonators whose angles of cut are located on the bulk wave C-mode zero temperature coefficient locus shall be studied as functions of: (a) the angles of cut of the resonator plates, (b) the plate geometries, (c) the mounting configurations, (d) the overtone number, and (e) any other variables which may affect vibration resistance.

The primary objectives of this study shall be to achieve a vibration sensitivity of 1×10^{-10} per g, and to define the design parameters and tolerances which will permit the achievement of such acceleration sensitivity, in a reproducible manner, for the vibration levels specified in MIL-STD-810C.

3. Secondary Objectives

a. 1×10^{-9} warmup in three minutes after application of power.

b. 1×10^{-9} retrace.

c. 1×10^{-11} per day aging at 100° C, after two weeks stabilization.

d. - 120 dB per Hz spectral purity at 1 Hz away from carrier.

e. 1 x 10^{-12} short term stability for 0.2 to 100 seconds.

f. To correlate vibration sensitivity with static acceleration sensitivity.

g. To investigate optimal enclosure for vibration resistant crystal resonators, including the ceramic flatpacks.

2. APPROACH

The basic approach is to cut corrected premium Q swept quartz bars at a constant ϕ angle of 23.75°, and vary θ over the range of 33.75° to 34.25°. By careful x-raying techniques, we will define a series of curves which will enable us to define the proper angles of cut to yield crystals with a specified upper turnover temperature.

The "SC" temperature characteristics are of a cubic nature. They vary from the AT, in that the inflection point is near 100° C as opposed to 25° C. Thus, the 'SC' crystals normally function on the left hand side of the cubic curve inflection point, while the 'AT' crystals function on the right side of the curve.

To obtain improvement in the "g" sensitivity, we are evaluating the mounting points, the location of the bonds, the bonding materials and the mounting structure.

The crystal designs, i.e., physical dimensions and overtone numbers are being modeled after similar AT cut crystals. Design sheets will be made available initially and as changes are made.

3. PROGRAM PROGRESS

The major accomplishments of the first six-month period are as follows:

A. Completed literature search on the suppression of the 'B' mode in doubly rotated 'SC' cut crystals.

B. Determined that the mounting points (locations of thermo compression bonds at the edges of the crystals) have a first order effect on the 'g' sensitivity.

C. Developed a series of extra process controls to minimize yield loss or potential failures.

D. Refined X-ray and quartz cutting techniques to minimize the need for angle correcting prior to lapping and polishing the blanks.

E. Discovered that the resistance of 5 MHz, fifth overtone 'SC' crystals can vary significantly over temperature.

F. Fabricated one crystal (serial number 1380), which is a 5 MHz, fifth overtone 'SC' crystal and has a 'g' sensitivity of less than 1 $PP10^{10}/g$ in any direction.

G. Fabricated 15 other SC cut crystals whose vibration sensitivities range from 1.4 to 12.6 $PP10^{10}/g$.

H. Located a source of gold clad nickel ribbon to improve thermo-compression bonding strength and precision.

4. TEST RESULTS AND EVALUATIONS

Results obtained during the first six-month reporting period:

A. The literature search performed yielded no hope of suppressing the 'B' mode by mechanical means[1]. Any thought of using a damping material on the surface of the crystal must be disregarded. This approach would seriously unbalance a structure that we are attempting to make as rigid and uniform as possible. The 'B' mode suppression may be safely left to the circuit designer.

NOTE: A recent Frequency Control Symposium Paper by Filler and Vig, "Fundamental Mode SC Cut Resonators", showed that it may be possible to suppress the 'B' mode by design.

[1] J. L. Saunders & D. L. Hammond
Scientific Radio Products
Loveland, Colo.
16 September 1956 to 26 June 1959
WADC Contract AF33(600)33889

B. In conjunction with Item A, we have found correlation between the location of thermo-compression (TC) bonds and the 'g' sensitivity. The bonds must be centrally located on the bonding flat of the crystal and the tool impression must be limited in size and preferably centrally located on the axis of the ribbon. The first five crystals subjected to vibration tests had the following results:

TABLE I*

Crystal	$PP10^{10}$	Comments
1370	1.4	See Figure I-1
1371	4.2	See Figure I-2
1373	6.5	See Figure I-3
1375	7.0	See Figure I-4
1376	1.4	See Figure I-5

*The above data are peak to peak readings about a 360° rotation as shown in Graph III-1.

The need for centrally locating the bonds is apparently caused by the establishment of mechanical couples in the crystal structure. Because the sample is small, re-processed and newly fabricated crystals are being photographed prior to sealing. Results will then be compared with the photographic evidence. Our goal is to find the relationship between the size and location of the edge bonding points and the turn-over curve, i.e., frequency versus acceleration of gravity in any direction.

By re-processing the same blanks several times, we hope to separate the mounting effects from any characteristic inherent in the blank itself.

C. Extra processing controls that have been installed are:

(1) The measurement of each crystal after electrode deposition prior to mounting, for frequency and resistance. The normal procedure was to check two crystals per lot. By expanding our data base we can improve the yield and segregate the crystals that may have been damaged in lapping.

(2) A new crystal cutting form has been implemented. This allows us to keep track of the blank identity through a bar of quartz as well as measuring the θ, θ'', ϕ and ϕ' of each crystal, where θ'' and ϕ' are the angles set on the saw table and measured directly by the X-ray goniometer. They are related by the equations

$$\theta = \tan^{-1} (\tan \theta'' \cos \phi)$$

$$\phi = \sin^{-1} \frac{\sin \phi'}{.7857}$$

If any correcting is required, this can be detailed, and then the blanks rechecked.

(3) Extra sample crystals are being processed with each lot to insure that we have sufficient test crystals for TC bond pull tests.

(4) Frequency versus temperature runs are made prior to tuning (final adjustment to frequency), after tuning, and after sealing, to insure that there has been no frequency shift. Resistance is also measured and plotted over temperature.

D. As previously mentioned in C(2). we are keeping track of all quartz blanks as they are cut from the bar. Our initial results (in-house as well as from outside sources) were sporadic. Correction was either not required or the blanks were as much as 45 minutes off, requiring an inordinate amount of correction, which was sometimes impossible. Our present in-house cutting system, with inspection controls, allows us to cut within two (2) minutes of θ", 65% of the time. The balance of the blanks are between two and eighteen minutes off, all of which are easily correctable. The worst blanks are usually the first five off of any bar. Much of our success and improvement can be attributed to the correcting of the bar prior to cutting. In these operations, we lap the -x and +z surfaces and verify that these surfaces

are normal to the X and Z axes within one minute of arc. We have also developed a computer program used at the X-ray to directly convert the dial readings to θ and ϕ, the specified angles of cut.

Following the suggestion of J. Vig, DELET-MQ, we plan to inspect all quartz blanks for quality. By selecting only those blanks with a minimum of etch pits, we will perhaps eliminate one factor in the variability of the frequency versus acceleration relationship.

E. The crystal resistance of some units has been found to vary over temperature. We have not yet determined the cause of this phenomenon. Further, several crystals show a rise in resistance at or near turn-over. Graphic and tabular data are attached. See Graphs II-1 to II-3 and Table II.

F. Crystal Serial Number 1380 exhibits the following characteristics under acceleration:

Axis	PP10^{11}/g Change
X	2
Y	1
Z	9

This crystal is thus less than 1 PP10^{10}/g in any direction, and the turnover test correlates with the results obtained on the vibration table, where accelerations as high as 24 g's were reached.

Turnover data and sideband plots are attached. See Graphs III-1 and Sideband Plots III-2, III-3 and III-4. The Sideband Plots are "noisier" than normal due to a defective amplifier. Future plots will be much clearer.

G. Our present TC bonded crystals use an aluminum clad nickel ribbon. The aluminum side of the ribbon is bonded to the plated edge of the crystal with heat and pressure. By evaluating gold coined onto nickel ribbon[2], we hope to make two improvements. First and foremost, is the ability to more accurately center the bonds on the edge of the crystal. Second, we will remove one intermetallic bond from the crystal structure.

5. PROPOSED OBJECTIVES FOR NEXT 6 MONTH PERIOD

A. Finalize resonator designs.

B. Evaluate gold coined to nickel ribbon as a mounting structure.

C. Fabricate fifty to one hundred blanks for each frequency of doubly rotated quartz crystals (5, 10, and 20 MHz).

D. Detail effects of mounting points on 'g' sensitivity.

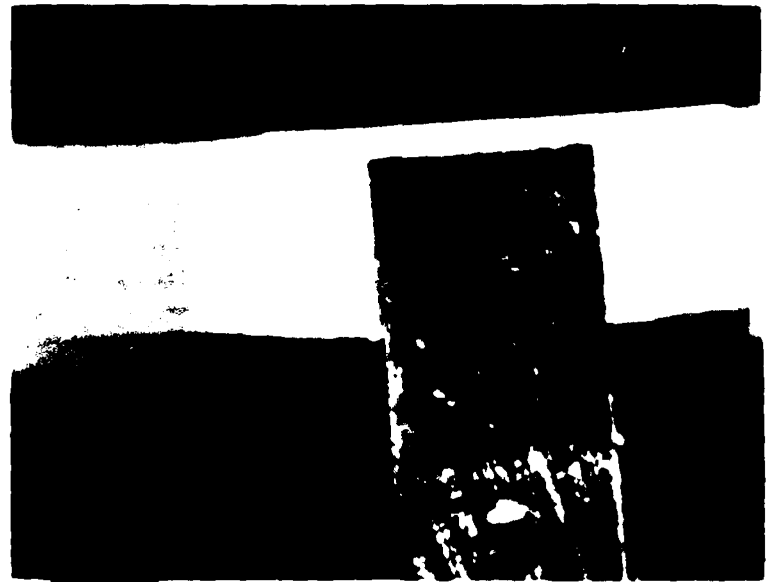
E. Evaluate new mounting structure(s).

[2] A sample of nickel ribbon with a coined gold pyramid attached, was received from Technical Materials, Inc. (TMI). The new material is .003 inch thick #270 nickel, dead soft (fully annealled), with a .005 inch diameter gold ribbon coined on to the surface.

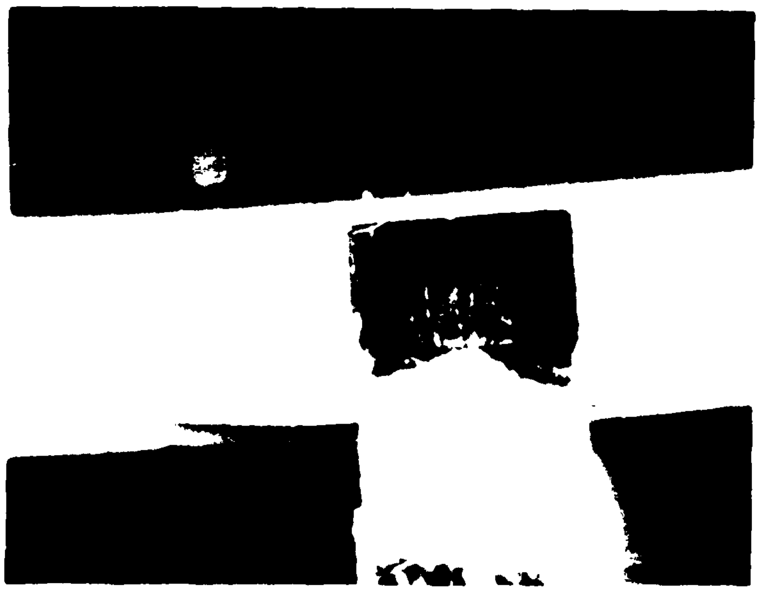
TABLE II

T(°C)	PAR.	SERIAL NUMBER 3644	3645	3646	3647	3648	3649	3650
25	FREQ	4999906	4999816	4999887	4999908	4999922	4999912	4999913
	RES	410	380		270	270	250	316
30	F	4999927	4999900	—	—	—	—	—
	R	406	398	—	—	—	—	—
50	F	4999979	4999963	—	—	—	—	—
	R	342	361	—	—	—	—	—
60	F	—	—	4999983	4999979	4999990	4999988	4999989.7
	R	—	—	330	270	300	300	300
65	F	4999990	4999984	4999987	4999980	4999992	4999991	4999993.4
	R	336	324	250	270	300	270	276
70	F	4999990	4999988	4999990	4999979	4999993	4999992	4999992.9
	R	324	324	250	270	300	250	248
75	F	4999989	4999989	4999991	4999978	4999992	4999992	4999991.0
	R	330	280	260	285	315	250	268
80	F	4999986	4999988	4999991	4999974	4999989	4999990	—
	R	294	273	250	260	300	250	—
85	F	4999981	4999987	4999990	4999970	4999987	4999989	—
	R	300	318	250	260	300	250	—
90	F	4999975	4999984	—	—	—	—	—
	R	300	321	—	—	—	—	—

1.6X



1.6X



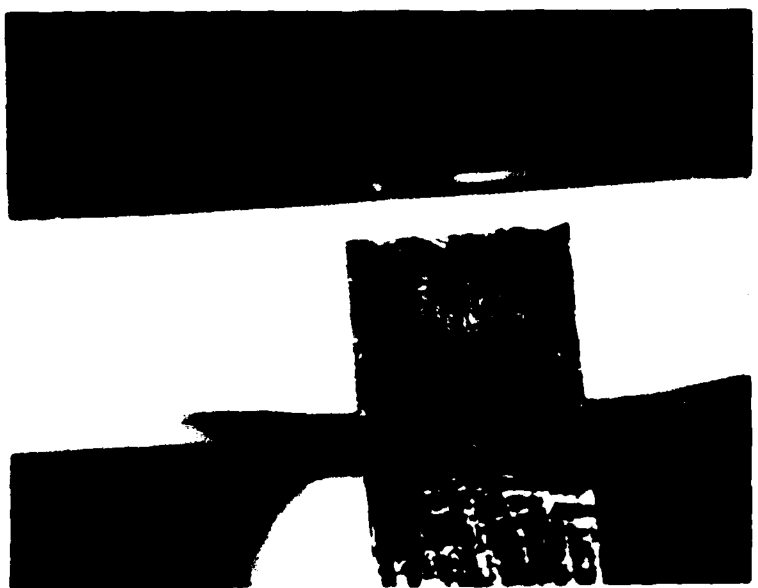
1.6X

Figure I-1

Nonactive bond well located. Both active bonds slightly high. One active bond toward right side of flat.

1.6X

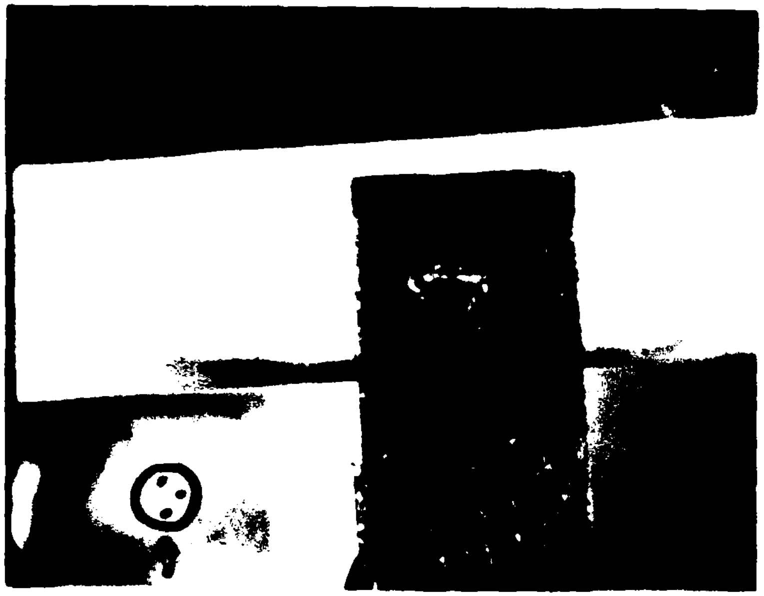
1.6X



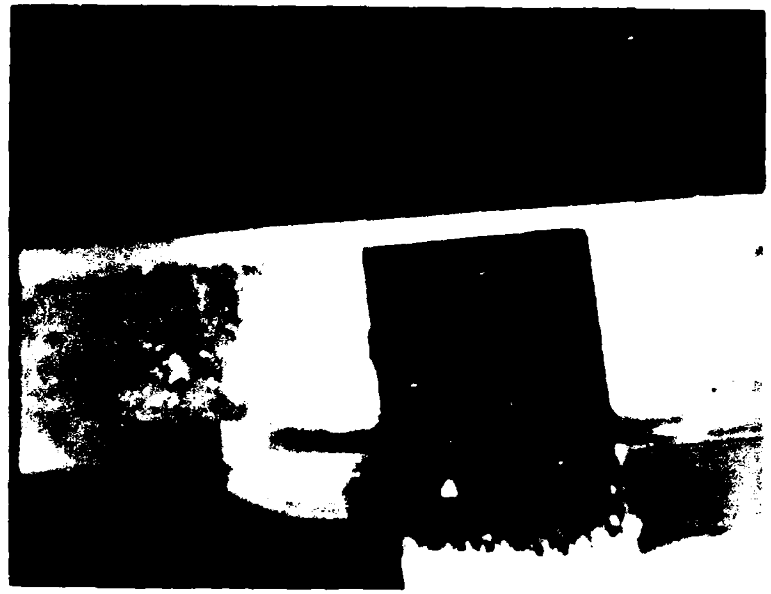
1.6X

Figure I-2

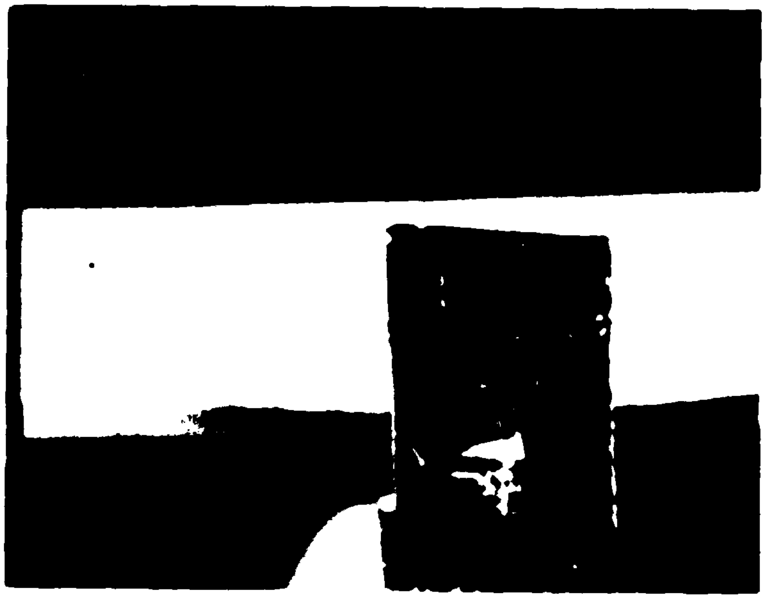
Nonactive bond high and to right. Active bonds high, and one slightly to right. One ribbon has excess material above crystal flat.



1.6X



1.6 X



1.6 X

Figure I-3

Nonactive bond and one active bond *are high other active bond* is centrally located. Small kink in active bond that is high.

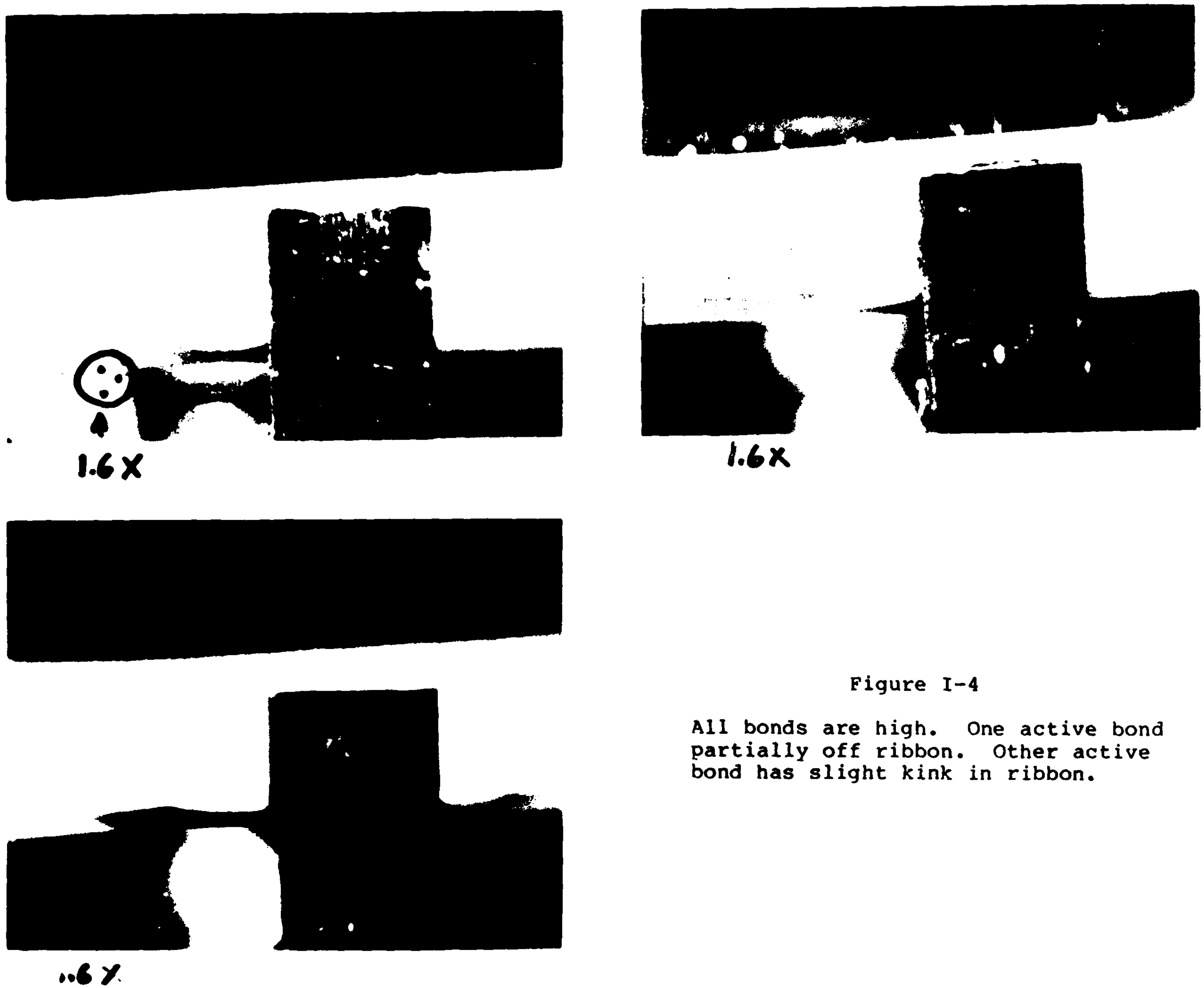
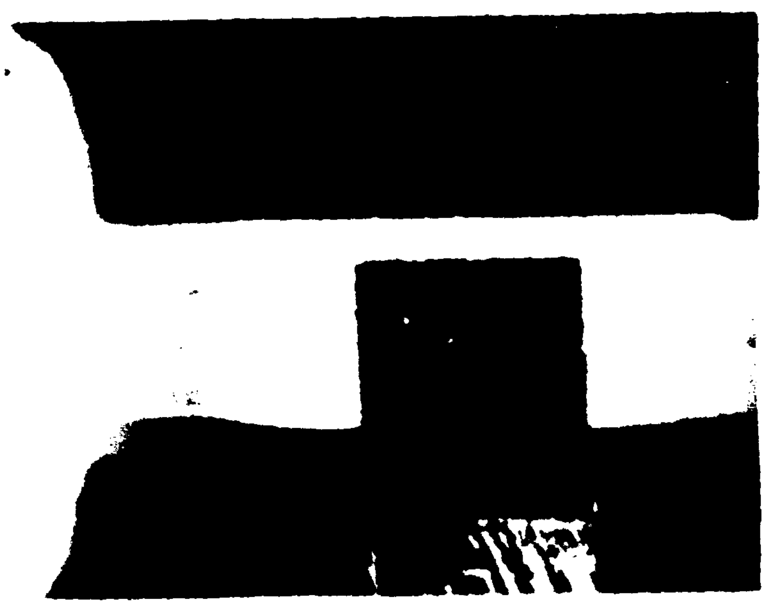
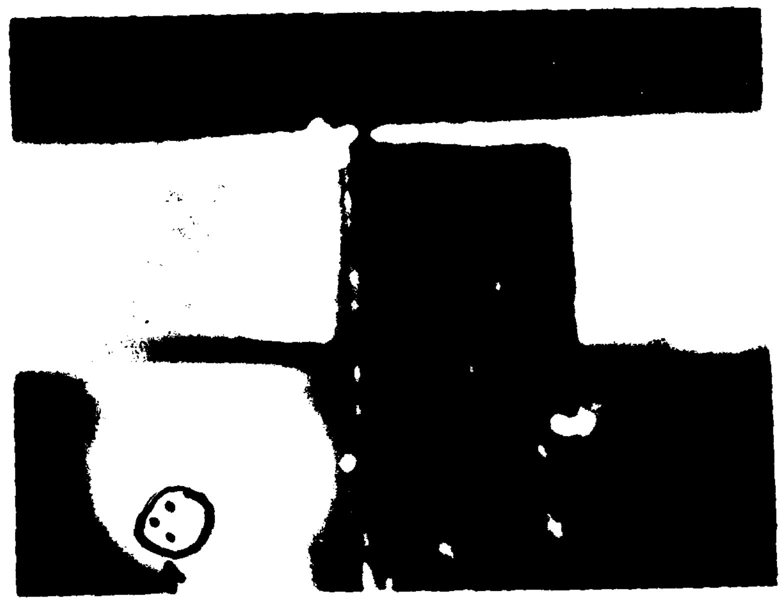


Figure I-4

All bonds are high. One active bond partially off ribbon. Other active bond has slight kink in ribbon.



1.6X

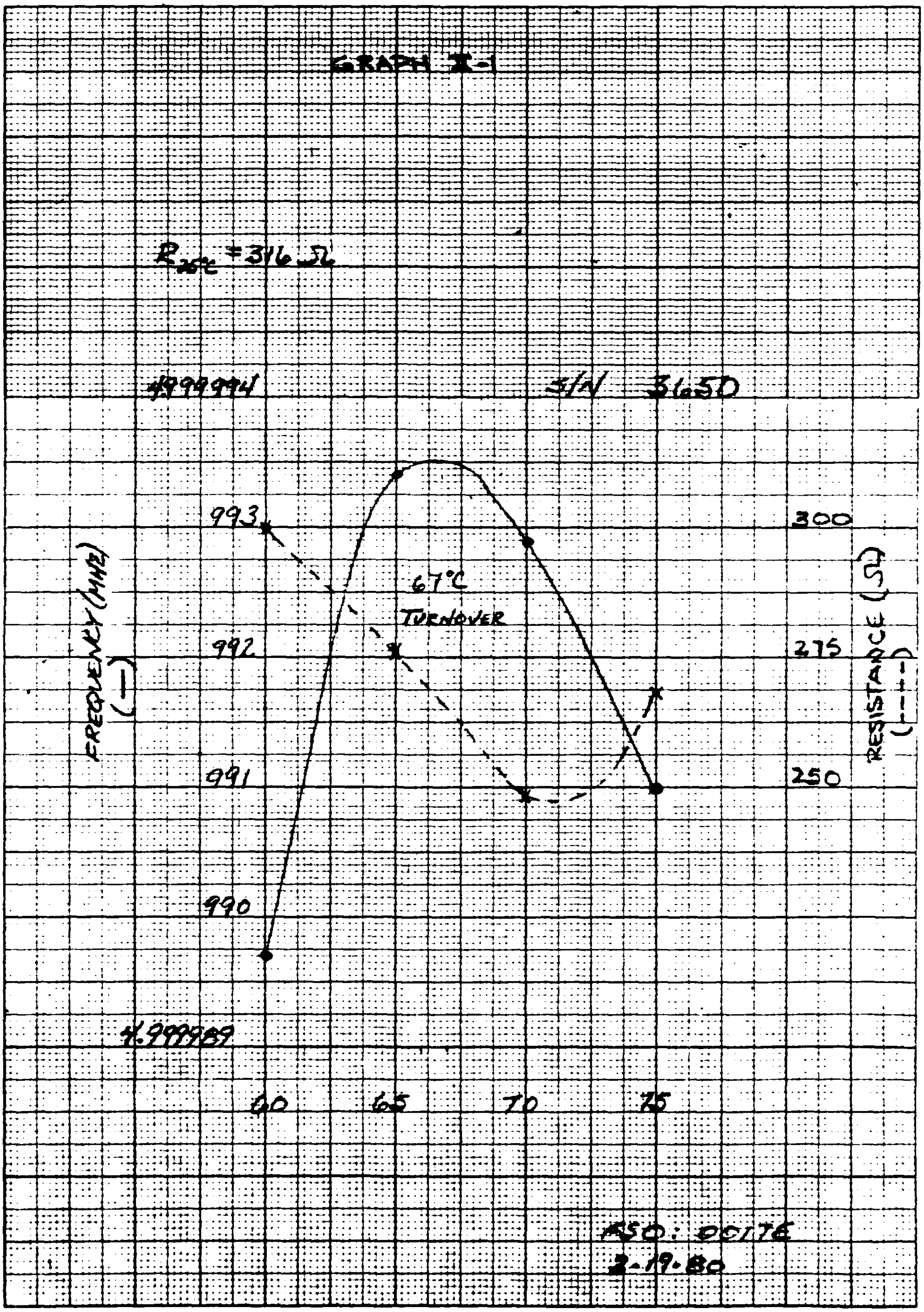


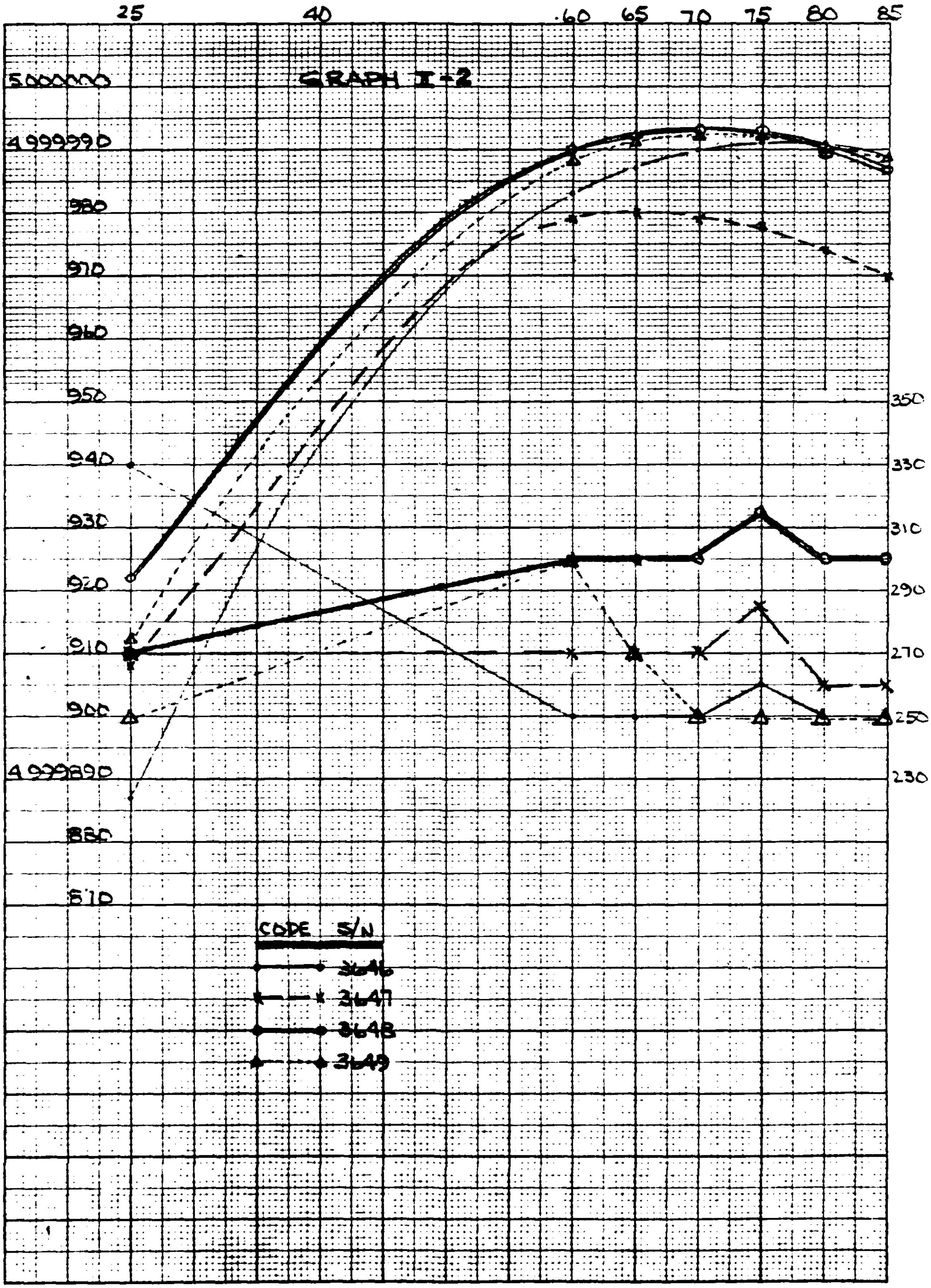
1.6X

1.6X

Figure I-5

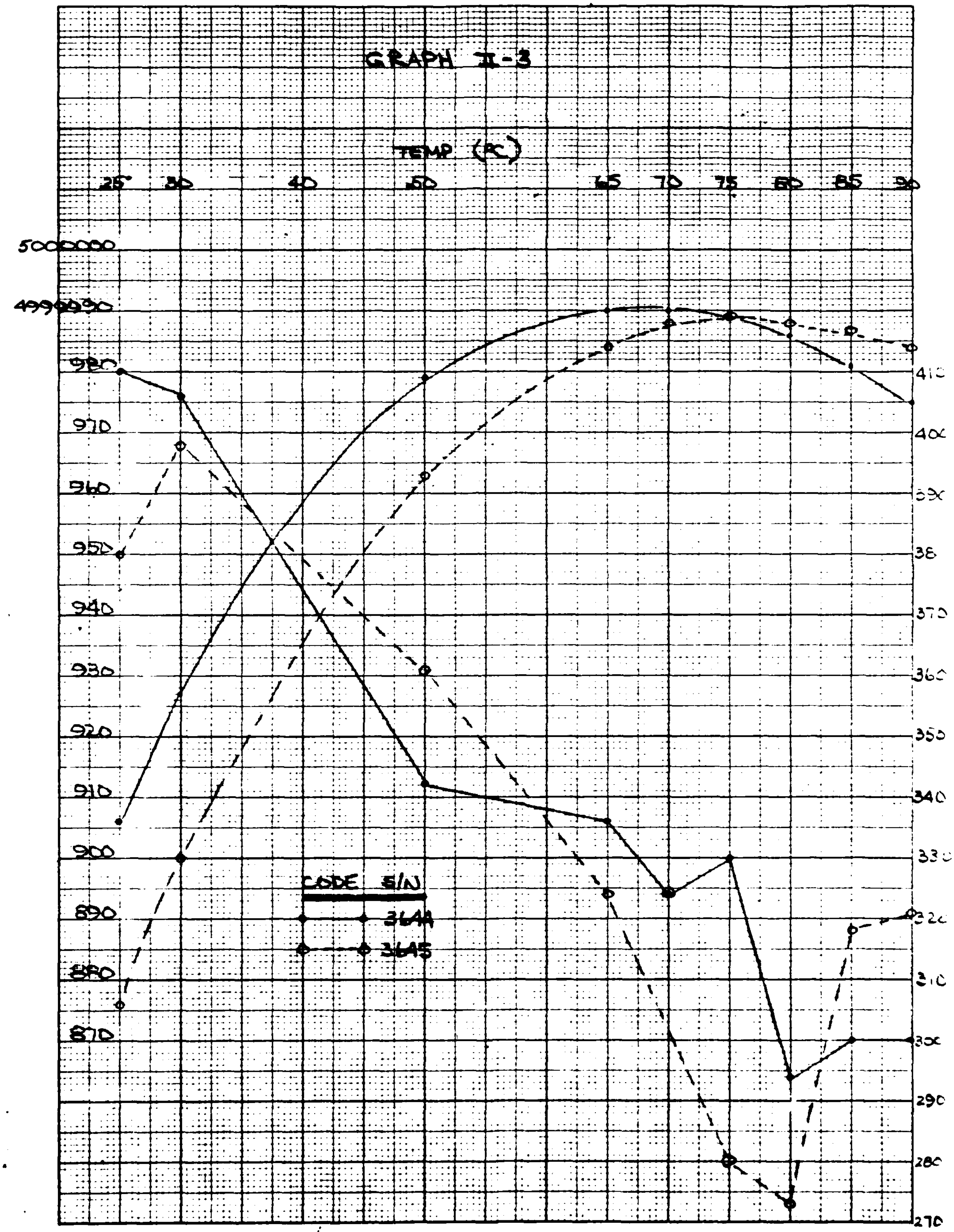
All bonds slightly high. One active bond slightly to right. Excess ribbon on one active bond.

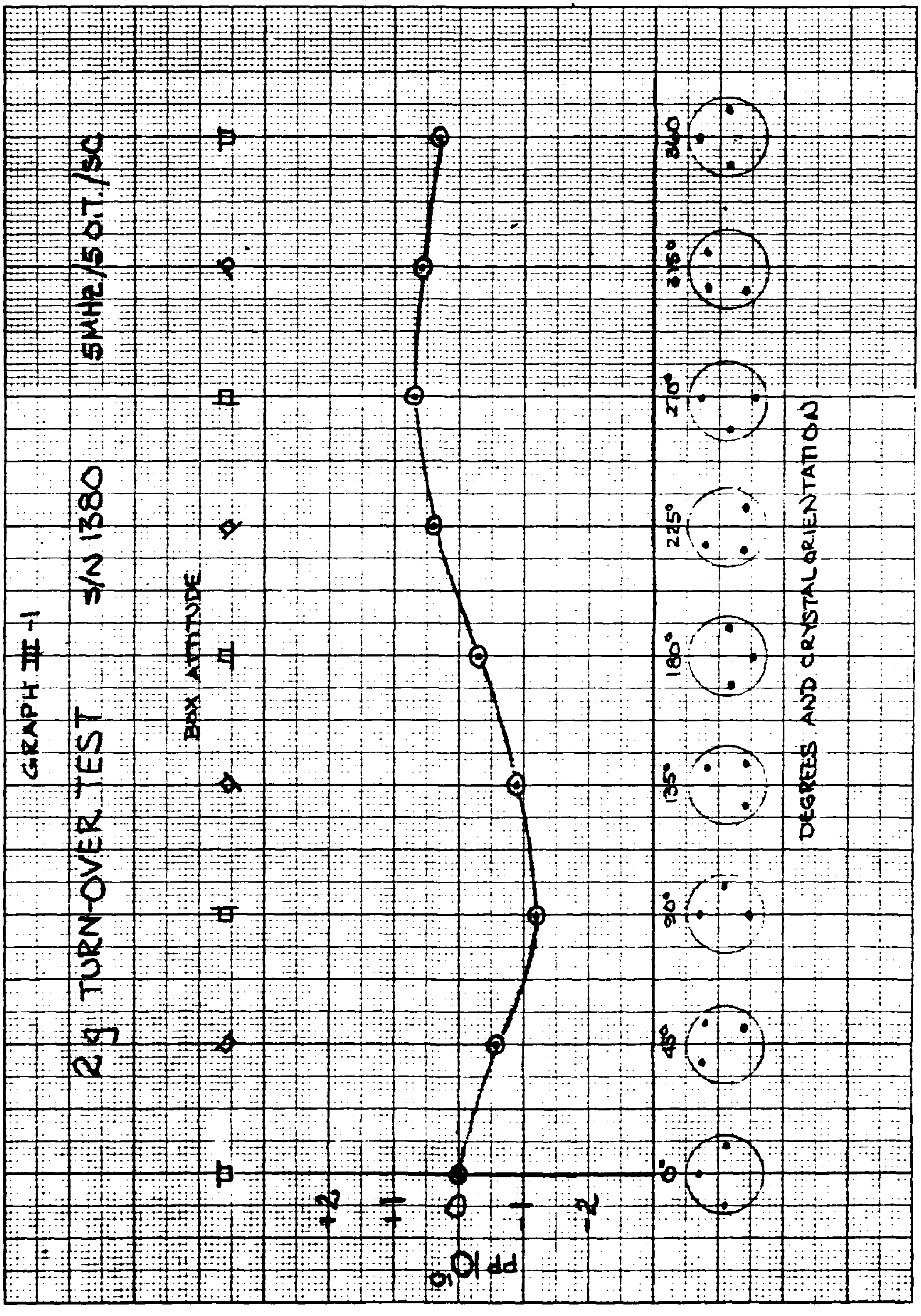

GRAPH X-1
R25°C = 316 Ω
4.999994
S/N 3650
993
992
991
990
4.999989
FREQUENCY (MHz)
(—)
300
275
250
RESISTANCE (Ω)
(- - - -)
67°C
TURNOVER
60
65
70
75
RSO: OCITE
3-19-80

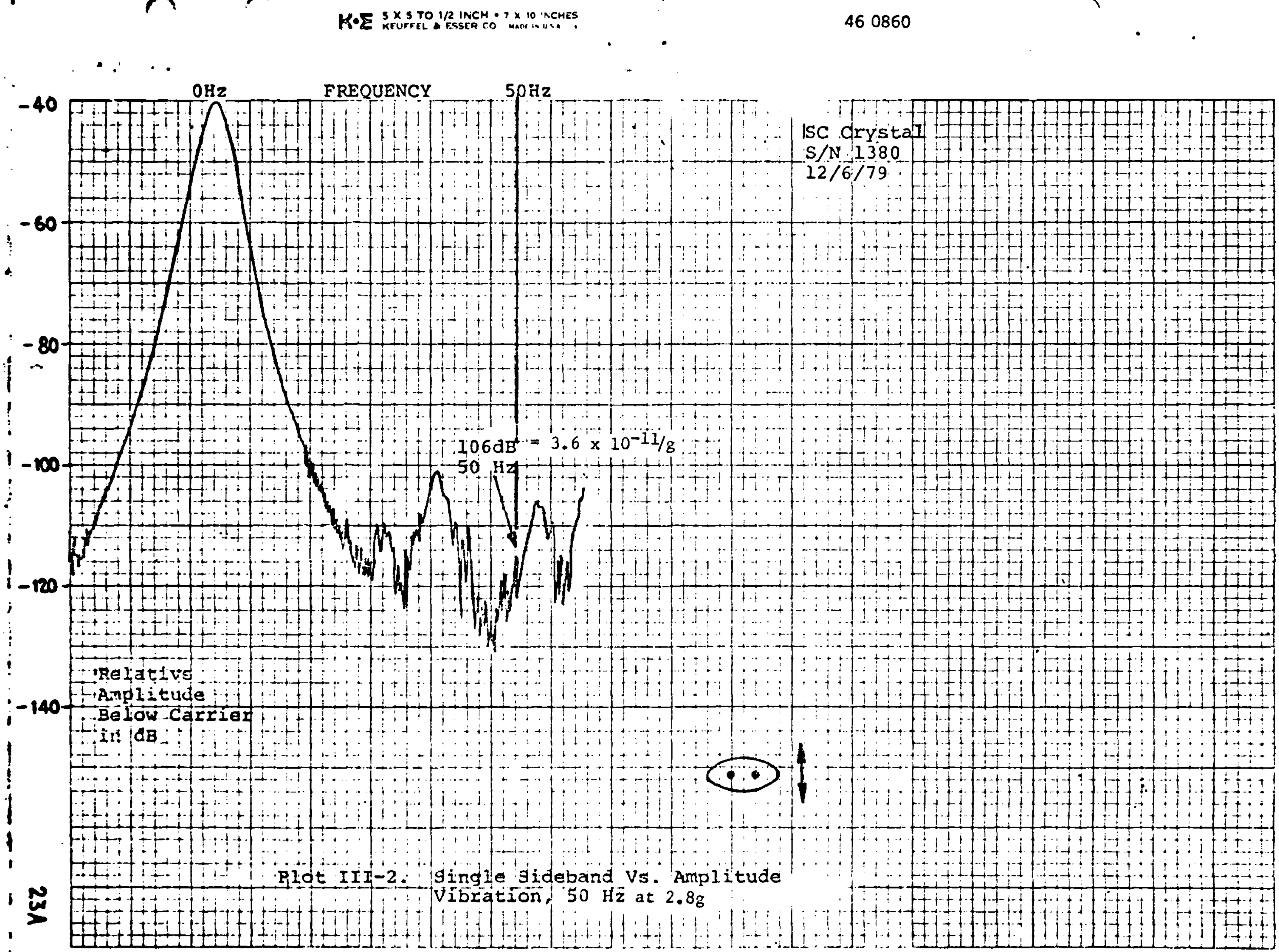


46 1240

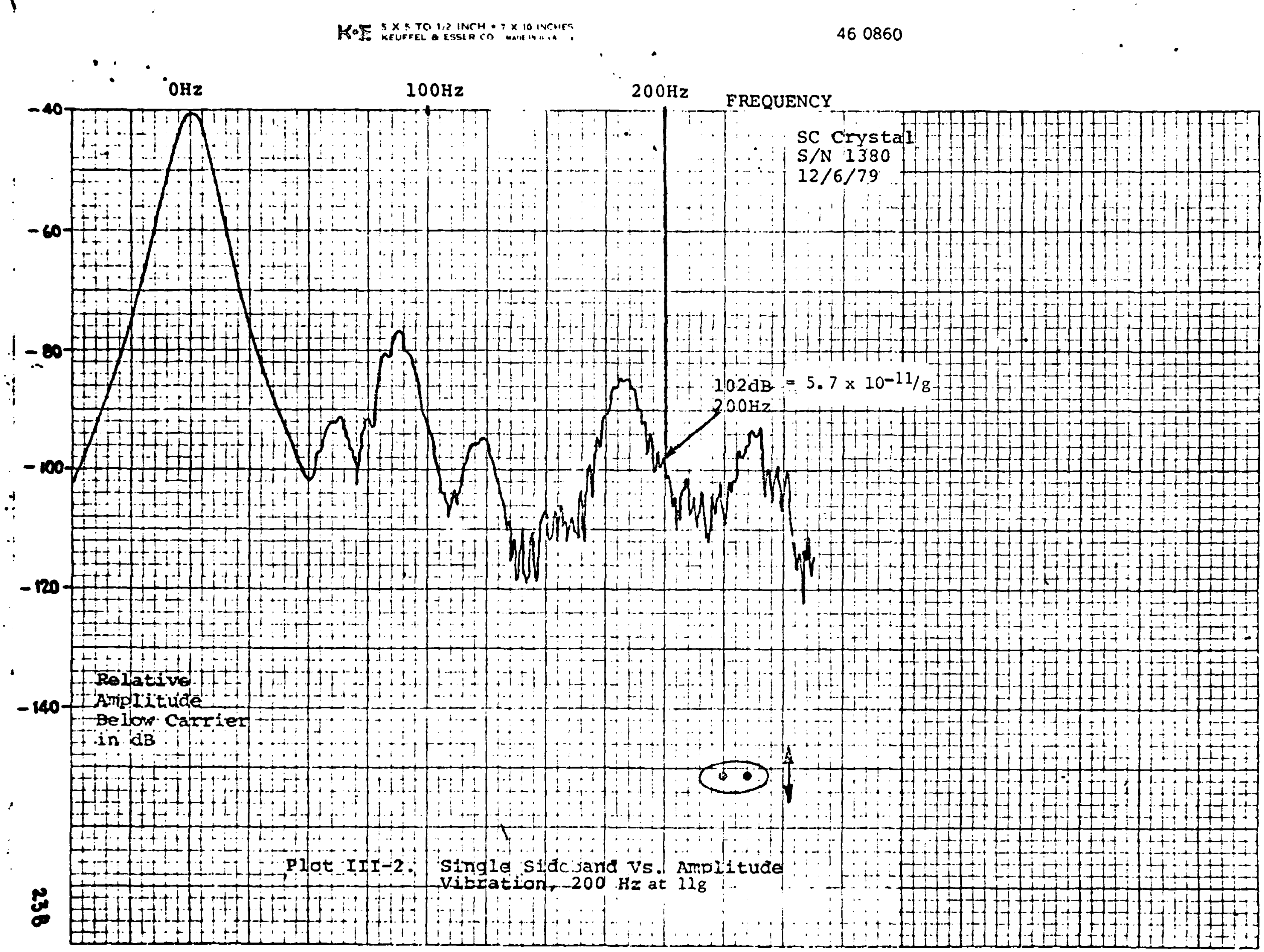
K•E 20 X 20 TO THE INCH • 10 X 10 TO THE HALF INCH
KEUFFEL & ESSER CO. MADE IN U.S.A.


GRAPH II-3
TEMP (°C)
25° 30 40 50 65 70 75 80 85 90
5000000
4999990
980
970
960
950
940
930
920
910
900
890
880
870
410
400
390
380
370
360
350
340
330
320
310
300
290
280
270
CODE S/N
3644
3645

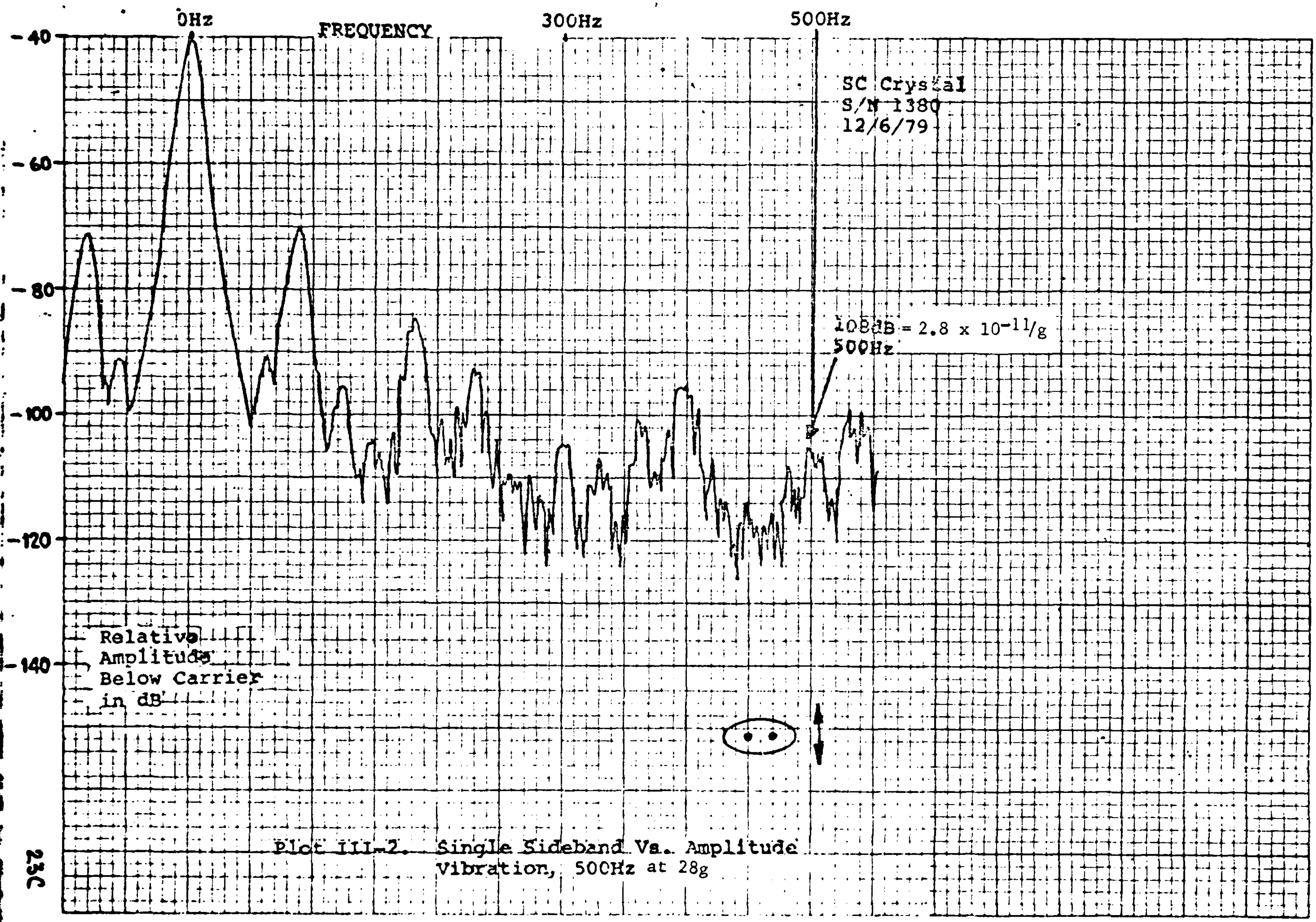

GRAPH III-1
29 TURN-OVER TEST S/N 1380 5MHZ/50T./SC
BOX ATTITUDE
DEGREES AND CRYSTAL ORIENTATION
PP10^9
+2
+1
0
-1
-2
0°
45°
90°
135°
180°
225°
270°
315°
360°



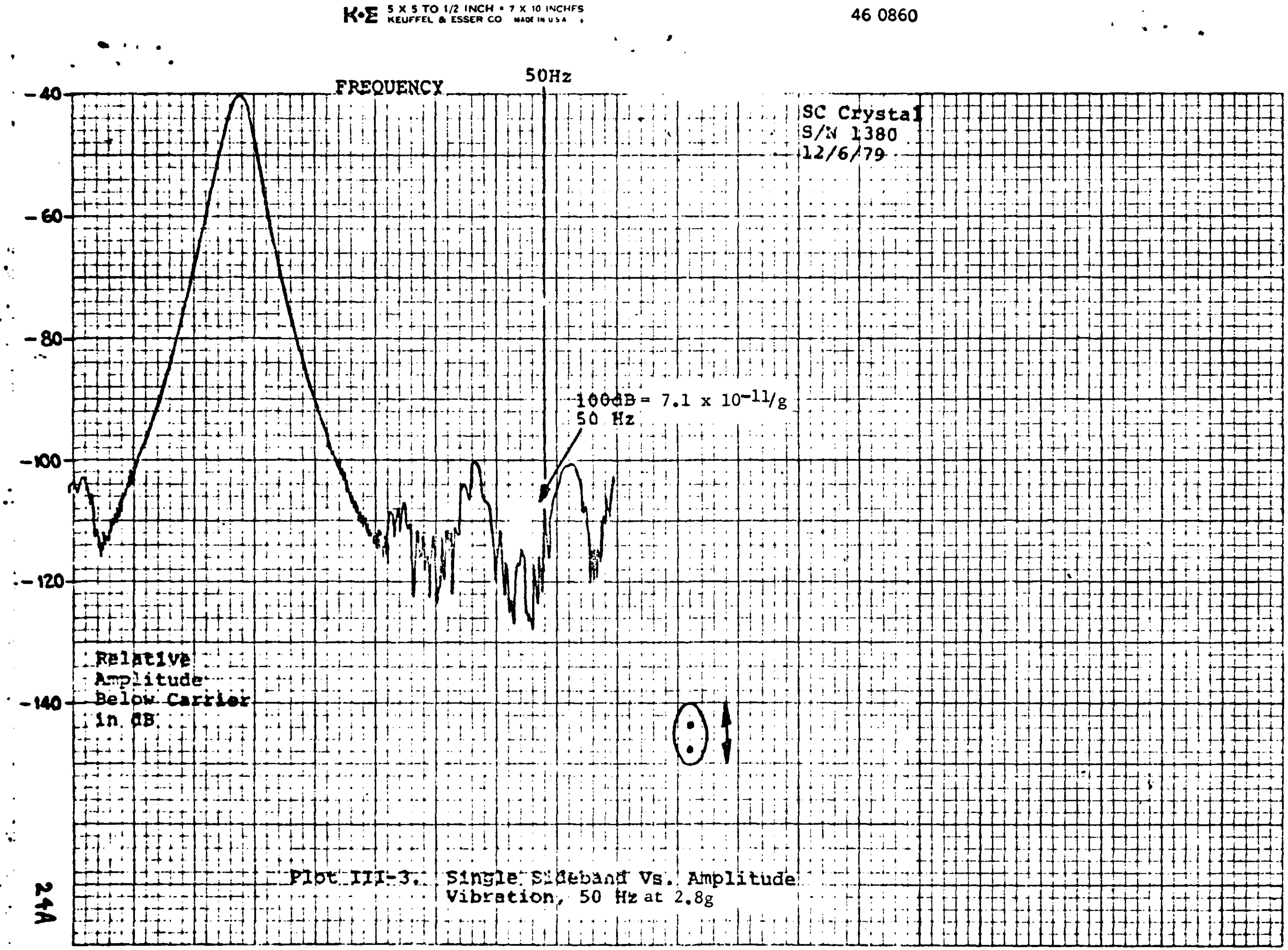
Plot III-2. Single Sideband Vs. Amplitude Vibration, 50 Hz at 2.8g



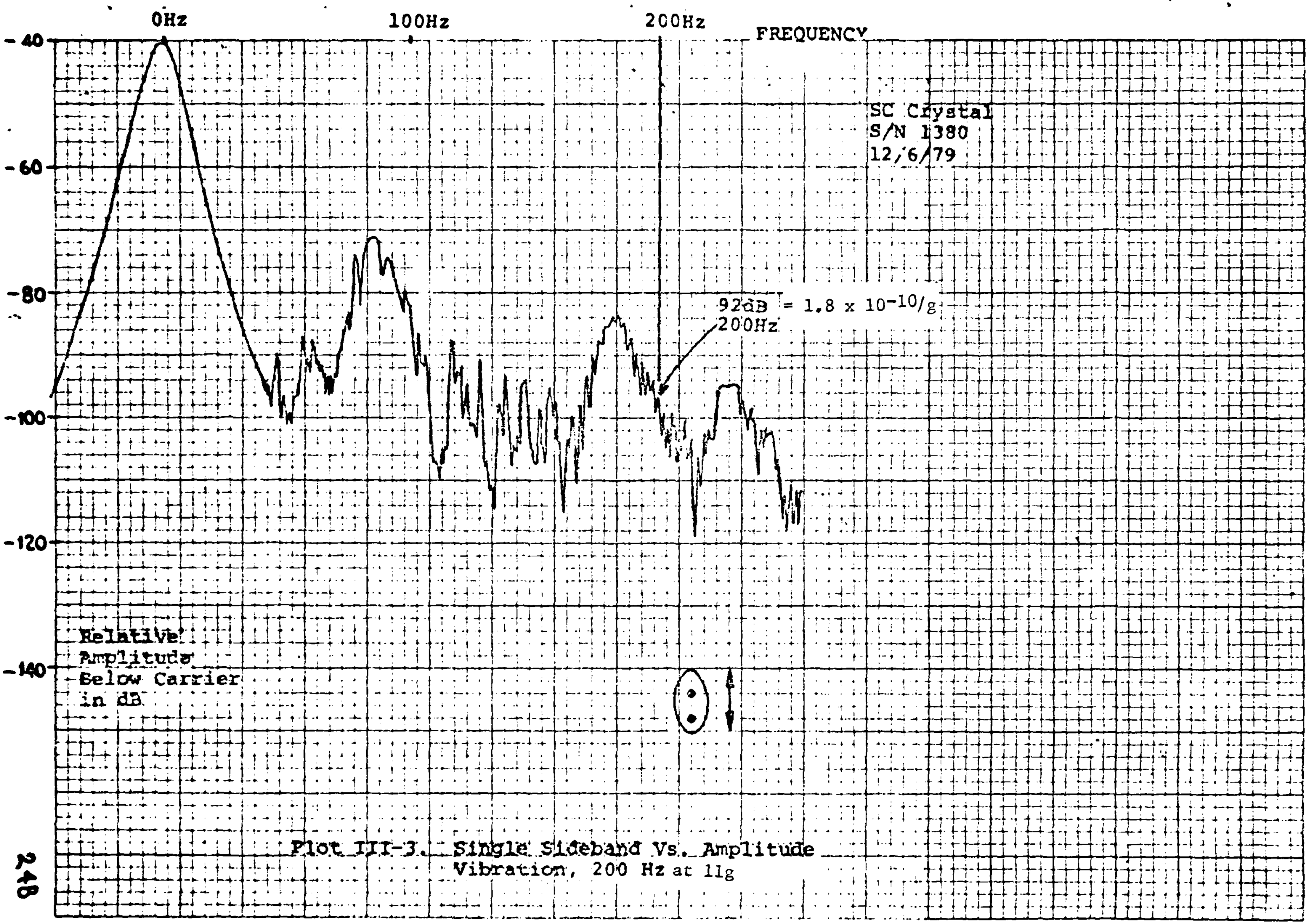
Plot III-2. Single Sideband Vs. Amplitude Vibration, 200 Hz at 11g



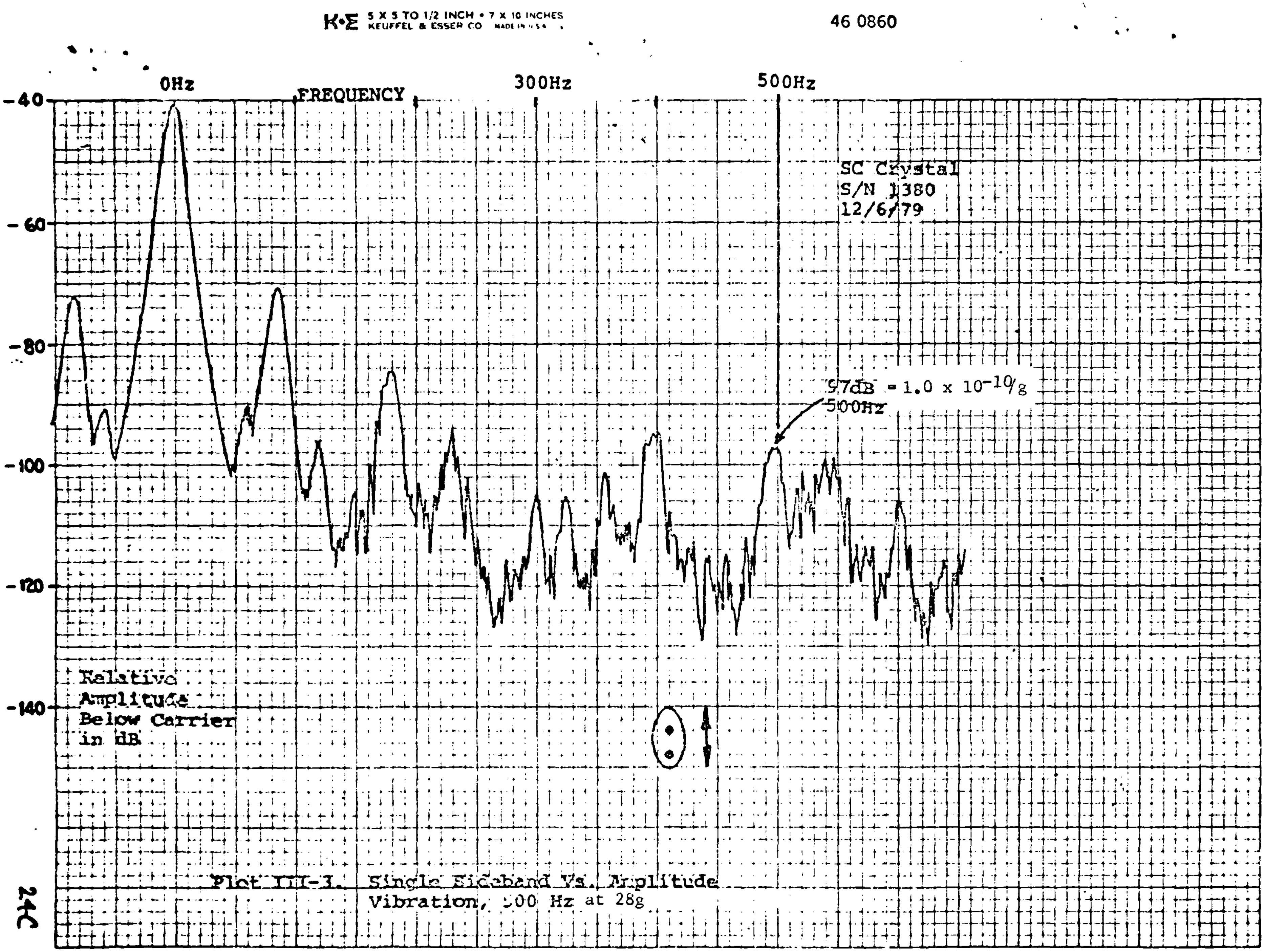
Plot III-2. Single Sideband Vs. Amplitude Vibration, 500Hz at 28g



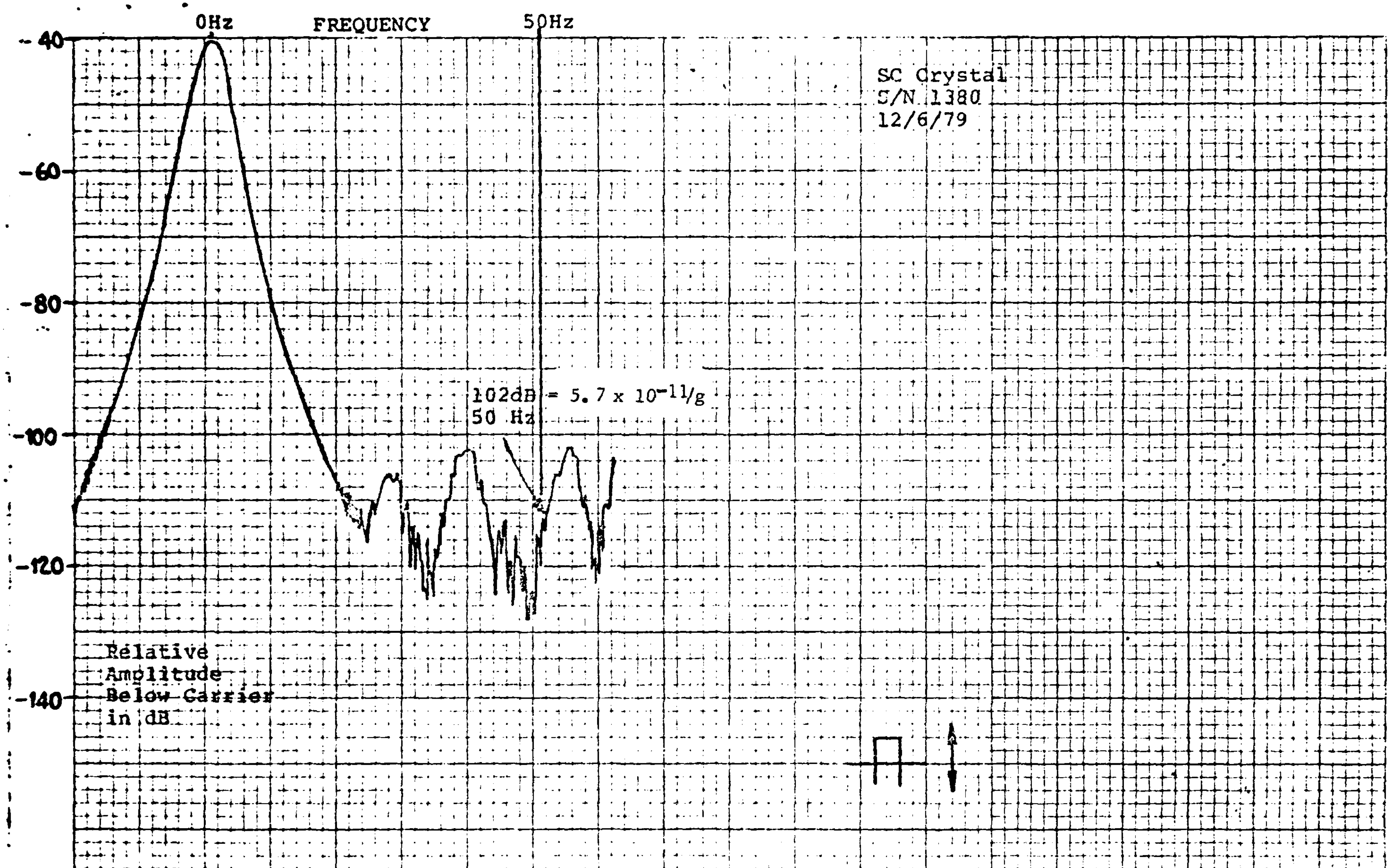
Plot III-3. Single Sideband Vs. Amplitude Vibration, 50 Hz at 2.8g



Plot III-3. Single Sideband Vs. Amplitude Vibration, 200 Hz at 11g

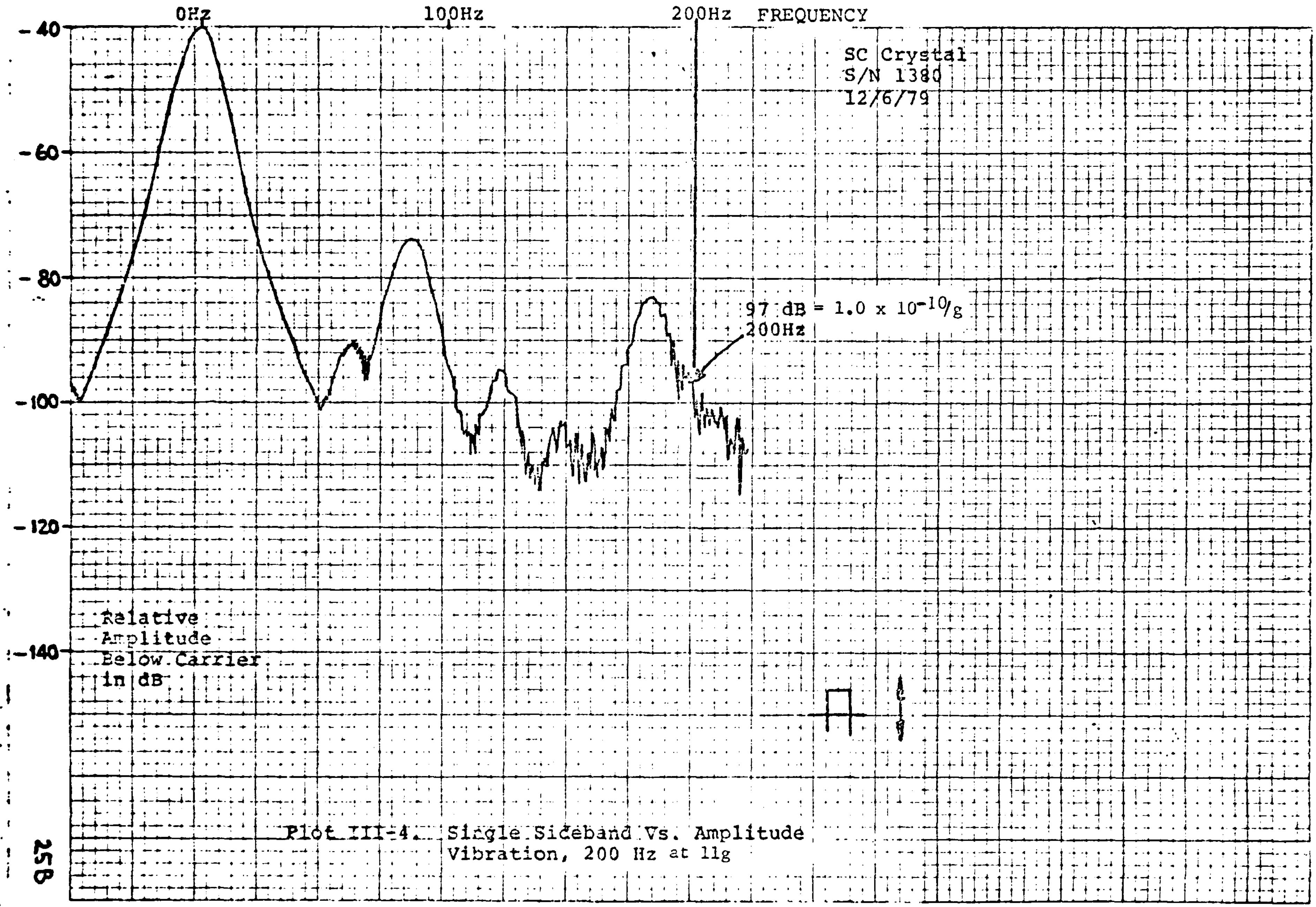


Plot III-1. Single Sideband Vs. Amplitude
Vibration, 500 Hz at 28g

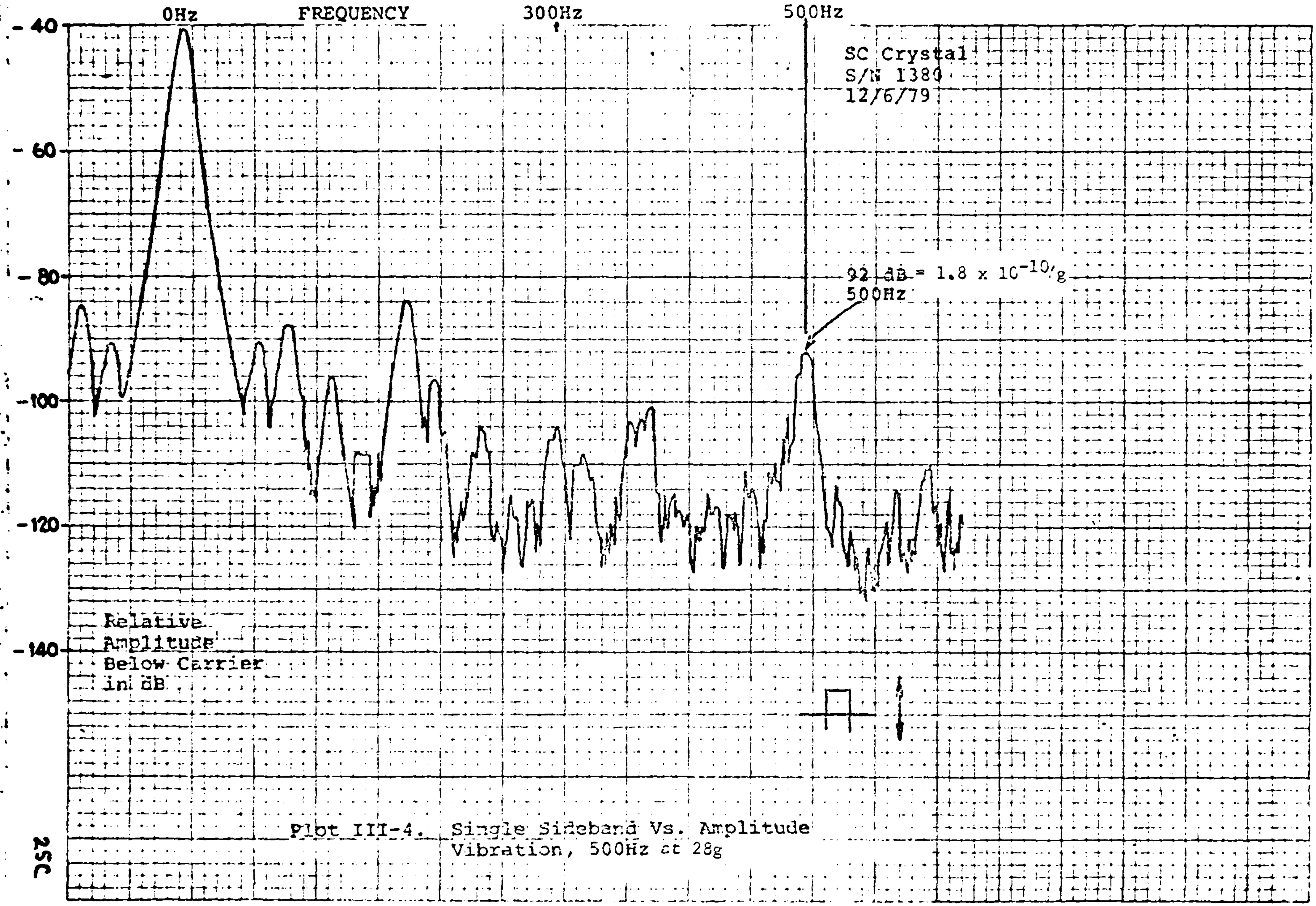


Plot III-4. Single Sideband Vs. Amplitude Vibration, 50 Hz at 2.8g

46 0860



Plot III-4. Single Sideband Vs. Amplitude Vibration, 200 Hz at 11g



Plot III-4. Single Sideband Vs. Amplitude Vibration, 500Hz at 28g

25C